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7.2 Status and plans for implementing algorithms at the GSETT-3 IDC

Introduction

Research and development efforts at NORSAR have for quite some time focused on methods and procedures that could be useful in the data processing carried out at the GSETT-3 IDC. These efforts have given results in terms of new knowledge, ideas, advice and recommendations that have been communicated to the IDC, and also results in terms of products, like the prototype Threshold Monitoring system delivered to the IDC in October 1994.

For our FY96 R&D effort for ARPA, it is a requirement that new knowledge emerging from our research program should be delivered, installed and tested within the software infrastructure on the testbed at the GSETT-3 IDC. In practice, this calls for integration of most of the NORSAR deliverables within the new Detection and Feature Extraction (DFX) software that became operational at the IDC in January of this year. To comply with this requirement, we have made a considerable effort to study the DFX software and its structure, and a visit by members of our staff to the DFX developers at SAIC, San Diego, in April has greatly facilitated this undertaking. This contribution summarizes the status of our software deliveries so far, as well as further plans.

Software delivered so far

The visit to SAIC, San Diego, provided an opportunity to agree on a delivery schedule for NORSAR contributions to the IDC software. It was agreed that the first products to be delivered should be software for IDC processing of data from the NORSAR teleseismic array in DFX, as well as certain DFX extensions to accommodate STA calculations for the Threshold Monitoring system. Following a period of intensive software development and testing, these products were delivered to SAIC, San Diego, on 18 June 1996. Provided that no severe difficulties are encountered during the final integration and testing to be carried out by SAIC, San Diego, the intent is to have this new software operational at the IDC as part of the planned 1 July release of DFX. Details on the software delivered so far are given in the following.

NORSAR processing algorithms

A technical refurbishment of the NORSAR teleseismic array was carried out during 1992-1995, and the array is now ready for participation in the GSETT-3 experiment as a primary station. The array has 42 short-period vertical sensor instruments (Teledyne Geotech 20171-0104) and 7 three-component broadband instruments (Teledyne Geotech KS54000P). The instruments are logically grouped into 7 subarrays, each with 6 short-period and one three-component broadband instrument. The array diameter is approximately 60 km, and each subarray diameter is in the range 7-10 km.

The NORSAR array will differ significantly from the rest of the GSETT-3 stations, both in terms of array diameter and amount of data transmitted. Due to the array diameter, special processing techniques are required to fully utilize the array's potential for both signal detection and precise teleseismic slowness estimation. The IDC has a fairly standardized way of processing seismic array data, using DFX to detect signals and perform feature extractions for each detection. Slowness estimates are obtained by standard broadband frequency-wavenumber (F/K) analysis. For NORSAR, plane wave beamforming will result in loss of signal power unless time delay corrections are applied (see Fyen, 1996). It is thus necessary to introduce time delay corrections both for the detecting beams and within the slowness estimation process.

The F/K analysis is a simple process to obtain signal power on a grid of slowness values within a frequency band, and the resulting slowness is taken to be the slowness corresponding to the peak power. In Fyen (1996), it is demonstrated that equivalent results are obtained by: 1) applying the standard F/K process and 2) prefiltering the data in the F/K frequency band and performing beamforming in the time domain for equivalent slowness values as for the F/K process (DFX function *"compute-beamform-fk"*), which is of course expected. Such a beamforming process requires more computer power than F/K computations, but time delay corrections for each beam point in slowness space are more easily adopted. It is also shown that the beamform method is more robust as compared to the "beampacking" method currently used at NORSAR. The "beampacking" method uses the trigger beam slowness vector as a starting point, and uses beamforming within a limited region surrounding the detection beam to refine the slowness estimate. The "compute-beamform-fk" will use the full specified slowness space, and calculate all beams. This will reduce the problem with sidelobe detections, since the alternative "beampack" process has a tendency to stay within the sidelobe.

During the visit to San Diego in April, NORSAR processing techniques were presented to the DFX development team, and two requirements were identified, the fulfillment of which would enable the processing of NORSAR data with DFX:

- Modification of the beam recipe and beamform code to include an option for time delay corrections;
- Addition of a new process which resembles F/K analysis for slowness estimation using time domain beamforming.

During the visit agreement was reached on a new beam recipe format which does not require any changes to former recipes for standard processing. In the new recipe, a beam may be defined in three different ways: by slowness and azimuth with no time delay corrections, by slowness and azimuth, with indication that time delay corrections should be used, or by giving absolute time delays. A new parameter defines a time delay correction data base file, which will be used in cases when the beam needs time delay corrections.

Following the San Diego meeting, the beamforming code has been changed, a time delay correction process has been included, and we are now able to do detection processing on NORSAR data using the new software. The "compute-beamform-fk" has subsequently been implemented into DFX at NORSAR, and testing demonstrates that we are able to process NORSAR array data with results comparable to or better than those regularly produced for the NORSAR array using our previous software ("beampacking"). As stated above, the new software was delivered to SAIC on 18 June.

DFX extension to accommodate STA calculation for the Threshold Monitoring system

The Threshold Monitoring (TM) system, developed by NORSAR, consists of three main modules. The first module computes short-term averages (STAs) for each station of the global network, using filtered traces for each 3-component station and a set of filtered beams for each array. The second module computes magnitude threshold on a global grid using the pre-calculated STAs, and the third module is used for visualization and analysis of the calculated magnitude thresholds.

In the prototype TM system delivered to the IDC in October 1994, the first TM module doing station STA amplitude calculations made use of a stand-alone program developed at NORSAR. Logically, the STA calculations should be done within the IDC signal processing module (DFX) as functions for database access, quality control, beamforming and filtering are already available in that context. During the visit to San Diego, we decided to take on the task of integrating the STA calculations for the TM analysis with the DFX program. In this way, the IDC operational team would also benefit from having fewer processes to monitor.

The DFX extension with the new STA calculations was delivered to SAIC on 18 June. As part of this DFX extension, we also modified the parameter files for the GSETT-3 primary stations to include STA calculations for the TM system. The following stations were included:

ABKT, ARCES, ARMA, ASAR, BDFB, BGCA, BJT, BOSA, CMAR, CPUP, DBIC, ESDC, FCC, FINES, GERES, HFS, HIA, KBZ, LBNH, LOR, LPAZ, MAW, MBC, MIAR, MJAR, NOA, NORES, NPO, NRI, PDAR, PDY, PFO, PLCA, SCHQ, SPITS, STKA, TXAR, ULM, VNDA, WALA, WHY, WOOL, WRA, YKA and ZAL.

To conform with the regular m_b calculations at the IDC, we have initially decided to compute the STAs from vertical component traces or beams filtered between 0.8 and 4.5 Hz with a 3rd order Butterworth filter. Both the STA length and the STA sampling interval is set to 1 s. In the code, the STAs are first calculated with the sampling rate of the original data, and the decimation to 1 s sampling interval is done by finding the maximum STA within each 1 s block.

For each of the three-component primary stations, only one STA trace is calculated from the vertical component channel and written to a cyclic disk file of 24-hour length. For each of the array primary stations, STA traces are computed from 15 beams deployed to cover the slowness range of P-phases. The beam steering points are given in Table 7.2.1.

Further plans for software delivery

Future plans for delivery of algorithms to the GSETT-3 IDC include making the prototype Threshold Monitoring system fully operational, provide a basis for improved onset-time estimation, contribute towards event post-processing, and making an effort to tune the signal processing for other GSETT-3 arrays than those already considered. Current status for each of these work items are briefly described in the following:

Threshold Monitoring system

Once the STA calculations for the TM system have been implemented in DFX, we will be ready to continue with making the rest of the prototype TM system operational. The resources needed for operational testing of the global threshold calculations and the visualization and analysis module are much less than those needed for the STAs, such that most of this work can be carried out at NORSAR utilizing the 256 Kbit/s link to the IDC.

As mentioned earlier, the first of the three current TM modules is completed and has been delivered to SAIC, and few changes are envisaged. The source codes for the second and third modules are closely integrated, and we have estimated the following numbers for the existing code (FORTRAN and NG-USE Macro language):

Number of FORTRAN files:	517
Number of NG-USE files:	340
Lines of FORTRAN code:	49930
Lines of FORTRAN comments:	25572
Lines of NG-USE code:	10402
Lines of NG-USE comments	1358

In addition to the modifications necessary to ensure stable operation, we would in the future like to extend the functionality of the TM system to include "optimized" site-specific monitoring as well as provide summary results requested by the international community. Another option which might be considered is to extend the global TM system to include surface waves. For integration of these options, the changes to the existing code are expected to be about 10% and additions about 30%.

Improved onset-time estimation

Our results on autoregressive onset-time estimation were presented to the DFX developers during the April visit. There is good indication that the algorithm we have developed will contribute to improve the onset-time estimation currently operational in DFX. This integration will, however, require that our onset algorithm is implemented as a self-contained C-function, and not in a signal processing macro language as currently available. We hope that our algorithm can be implemented in the IDC processing in conjunction with a DFX release later this year.

Event post-processing

We have during the last couple of months been experimenting with a post-processing scheme for events located in the Japan area, with the aim of obtaining more precise event location (both using automatic and/or analyst time picks). Our improved onset-time estimation routine is a key element in this research. During this research we have made several interesting findings on the use of arrival-time picks and master-event location techniques in this context of getting more precise event locations. Unfortunately, some of our results indicate that the use of master-event location techniques or regionalized traveltime curves is more complex than we previously anticipated. We will make an assessment of these problems to see what can realistically be achieved and then plan accordingly with respect to future deliveries of software for IDC processing.

Tuning of signal processing for GSETT-3 arrays

We have looked into the signal processing for the SPITS array and briefly the MJAR array for the purpose of tuning the signal processing parameters. From what we have seen, it may not be sufficient to change only the processing parameters in DFX to obtain good performance. From our point of view, it seems beneficial to make some extensions to the signal measuring methods. With our current understanding and knowledge of the DFX software, we consider ourselves to be in a position to provide such extensions, if required.

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Reference

Fyen, J. (1996): Time delay measurements and NORSAR large array processing, NORSAR Technical Report, June 1996, Kjeller, Norway.

Table 7.2.1: Array beam deployment for magnitude threshold calculations

Beam Name	Azimuth	App. vel. (km/s)
TM001	0.0	∞
TM002	0.0	11.5
TM003	60.0	11.5
TM004	120.0	11.5
TM005	180.0	11.5
TM006	240.0	11.5
TM007	300.0	11.5
TM008	0.0	8.5
TM009	45.0	8.5
TM010	90.0	8.5
TM011	135.0	8.5
TM012	180.0	8.5
TM013	225.0	8.5
TM014	270.0	8.5
TM015	315.0	8.5